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RESEARCH MEMORANDUM

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TRANSONIC AERODYNAMIC CHARACTERISTICS OF THREE W-PLAN-FORM WINGS HAVING ASPECT RATIO 8, TAPER RATIO 0.45, AND NACA 63A-SERIES AIRFOIL SECTIONS

By William D. Morrison, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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RESEARCH MEMORANDUM

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SUMMARY

An investigation has been made in the Langley high-speed 7- by 10-foot tunnel to determine the transonic aerodynamic characteristics of three wings having W-type plan forms, NACA 63A-series airfoil sections, an aspect ratio of 8, and a taper ratio of 0.45. Two wings had panel sweep angles of 45°. A 35° wing and one of the two 45° wings had thickness ratios tapered from 0.10 at the root to 0.06 at the tip; whereas the remaining 45° wing had a constant thickness ratio of 0.12. Panel junctures for all wings were at the midsemispan station. The test Mach numbers varied from 0.70 to 1.09 at Reynolds numbers of the order of 500,000.

The results of this investigation and a comparison with test results obtained from similar sweptback wings indicate that modification of the conventional 45° sweptback wing to a W plan form appreciably alleviates the large lift losses and unstable pitching-moment tendencies typical of relatively thick swept wings at transonic speeds. Use of this composite plan form provides a marked improvement in the high-lift pitching-moment characteristics but some increase in zero-lift drag at transonic speeds. The effects of the changes in thickness on the transonic lift and pitching-moment characteristics of the W wings were appreciably smaller than for swept wings of the same aspect ratio. Subsonic lift-curve slope, aerodynamic center, and lateral-center-of-lift locations for the W-plan-form wings could be predicted rather well by use of available theory.

INTRODUCTION

Sweptback wings having moderately high aspect ratios are known to be capable of obtaining high lift-drag ratios and, consequently, good range characteristics at high subsonic speeds; but in order to obtain satisfactory transonic stability characteristics, as well as acceptable supersonic performance, the wing thickness must be maintained at a low value. The utilization of such a thin high-aspect-ratio swept wing, however, presents formidable structural problems. Therefore, some means is needed by which the structural properties of a relatively thick wing can be retained while still obtaining satisfactory transonic stability characteristics and acceptable supersonic performance.

One approach that has been used to improve the aerodynamic properties of swept wings of high aspect ratio (also providing structural improvements) is the modification of the swept wing to an M or W plan form. It has been found from a preliminary investigation of such composite plan forms (refs. 1 and 2) that these plan-form modifications greatly improve the pitching-moment characteristics and aeroelastic properties. One significant disadvantage of the composite plan form has been the increase in minimum drag at transonic speeds and an increase in drag due to lift over a part of the speed range.

An investigation has been made in the Langley high-speed 7- by 10-foot tunnel to determine the basic aerodynamic characteristics of three high-aspect-ratio W-plan-form wings. These wings had midsemispan panel breaks - the inboard panel being swept rearward and the outboard panel swept forward. One of the wings had panel sweep of 35° and the remaining two had panel sweep of 45°. The 45° W-plan-form wings had geometric parameters identical to those of conventional swept wings previously investigated (refs. 3 and 4). These sweptback wings were investigated through a similar Mach number range, at the same Reynolds numbers, and under the same flow conditions as the wings of the present investigation. This paper presents the experimental results through a Mach number range of 0.70 to 1.09 at Reynolds numbers of the order of 500,000 of three W-plan-form wings of an aspect ratio of 8 and a taper ratio of 0.45. One of the 45° swept W wings had a constant 12-percent thickness and the other (as well as the 35° wing) was tapered in thickness from 10 percent at the root to 6 percent at the tip. Comparisons are made to determine the effects of sweep, thickness, and plan-form modification on the aerodynamic characteristics of the W wings.

SYMBOLS

All force and moment data presented are referred to the wind axes.

C_L	lift coefficient, $\frac{\text{Twice semispan lift}}{qS}$
C_D	drag coefficient, $\frac{\text{Twice semispan drag}}{qS}$
C_m	pitching-moment coefficient referred to $0.25\bar{c}$, $\frac{\text{Twice semispan pitching moment}}{qS\bar{c}}$
C_B	bending-moment coefficient due to lift measured about root chord, $\frac{\text{Bending moment}}{qSb/4}$
$C_{D_{min}}$	minimum drag coefficient at $C_L = 0$
ΔC_D	drag coefficient due to lift, $C_D - C_{D_{min}}$
q	effective dynamic pressure over span of model, $\frac{1}{2}\rho V^2$, lb/sq ft
V	free-stream velocity, ft/sec
S	twice area of semispan model, sq ft
$\bar{c}$	mean aerodynamic chord of wing, using theoretical tip $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft
c	local wing chord, ft
b	twice span of semispan model, ft
t	maximum local section thickness, ft
t/c	airfoil section thickness ratio
y	spanwise distance from plane of symmetry, ft

[redacted]

M	effective free-stream Mach number over span of model
M_l	local Mach number
M_a	average chordwise Mach number
Y_L	lateral center of lift, $100C_B/C_L$, percent semispan
α	angle of attack at root chord, deg

APPARATUS AND TESTS

Models

Details of the models are shown in figure 1 and the variation of the wing thickness ratio along the semispan is presented in figure 2. The W-plan-form models of this investigation were constructed entirely of steel with panel junctures at 0.50b/2. All three models had an aspect ratio of 8 and a taper ratio of 0.45. Two wings had 45° of sweep (sweptback inboard panel and sweptforward outboard panel) referred to the quarter-chord line, one having an NACA $63A_1012$ airfoil section and the other an NACA 63A010 section at the root chord tapered in thickness by straight-line elements to an NACA 63A006 section at the tip chord. The third wing had 35° of sweep and was tapered in thickness ratio from an NACA 63A010 section at the root to an NACA 63A006 section at the tip. Airfoil sections were measured parallel to the free stream.

Test Procedure

In order to test the semispan model in a region outside the tunnel boundary layer, a reflection plane was mounted about 3 inches from the tunnel wall. (See fig. 3.) The reflection-plane boundary layer was such that a velocity equal to 95 percent of the free-stream velocity was reached at a distance of 0.16 inch from the surface at the balance center line for all test Mach numbers. This distance represents about 2.7 percent of the model semispan. A gap of about 1/16 inch was maintained between the wing root-chord section and the turntable of the reflection-plane plate. A sponge seal was attached to the wing butt (touching lightly against the back of the turntable) to minimize leakage.

Mach number distributions in the test region without a model in the test position were obtained at a number of spanwise and chordwise locations by use of a static probe and were plotted as shown in figure 4.

[redacted]

From these contours an effective free-stream Mach number for a given model was determined using the relationship

$$M = \frac{2}{S}\int_0^{b/2} cM_a \, dy$$

Up to and through a Mach number of 0.93, there was essentially no chordwise or spanwise velocity gradient over the models. At the higher test Mach numbers, however, the presence of the reflection plane created a localized high-velocity field which allowed the small models to be tested up to a Mach number of 1.09 before choking occurred in the tunnel and, consequently, there were noticeable chordwise and spanwise gradients. These gradients resulted in a maximum velocity difference of 0.05 Mach number over the surface of the model. An investigation to determine the effects of these gradients has shown that test results of identical wings determined from two test techniques, where gradients were appreciably different, do not show large or consistent differences.

In general, the accuracy of the force and moment measurements can be judged by any random scatter of the test points used in presenting the basic data. In applying a technique that utilizes small reflection-plane models mounted in a localized high-velocity field, the reliability of the absolute values of some of the results, particularly the drag values, may be open to question. Experience has indicated, however, that valid determinations of incremental effects, such as those due to lift coefficient, Mach numbers, or changes in model configuration, normally can be obtained. A more complete evaluation of results obtained by techniques such as that used for the present investigation is given in reference 5.

Forces and moments were measured and recorded by means of an electrical strain-gage balance system. The angle of attack of the wing was measured by means of a slidewire potentiometer and calibrated galvanometer.

The range of test Reynolds numbers (based on $\bar{c}$) over the Mach number range for both the subject and comparison wings is presented in figure 5.

RESULTS AND DISCUSSION

Presentation of Results

Inasmuch as some of the aerodynamic parameters presented are not linear with lift coefficient, all slopes presented were measured through

[redacted]

zero lift up to a lift coefficient where there were obvious departures of the curves from linearity. The results are presented in charts and are arranged as indicated in the following table:

	Figures
Basic data	6 to 8
Effects of plan-form modification	9 and 10
Effects of thickness	11
Effects of sweep	12

Effects of Plan-Form Modification

The predominant effect of the composite W-plan-form modification on the lift and lateral-center-of-lift characteristics of swept wings of high aspect ratio appears to be the elimination of the large loss in loading which occurs over the outboard section of relatively thick swept wings at Mach numbers near unity. (See figs. 9 and 10.) This loss in loading was more severe for the 12-percent-thick wing than for the thinner sweptback wing with a tapered-in-thickness ratio; therefore, utilization of the W plan form produces the greatest gain on wings of the higher thickness level. The bending-moment data also indicate that the lateral-center-of-lift location remained almost constant for the W-plan-form wings up to the moderately high lift coefficients reached in the present tests. Separation over the outboard wing section which produces inboard movements of lateral center of lift is evident at very low lift coefficients for the swept wing.

As might be expected from the previous discussion, the pitching-moment characteristics in the low-lift range at Mach numbers near unity and in the higher lift range at all Mach numbers are markedly improved by use of W-type wings.

As has been found in previous investigations of composite plan-form wings, the zero-lift drag at transonic speeds is somewhat greater than that of the conventional swept wing. This increase in minimum drag for the W wing is probably due in part to the build-up of the boundary layer at the panel juncture and consequent larger wake losses at this section (ref. 2). At Mach numbers below force break, the drag due to lift is appreciably greater for the W wings; however, at transonic speeds, because of the severe flow separation over the outboard portions of the swept wing, the composite W-plan-form wings have somewhat lower drag due to lift.

[redacted]

Effects of Thickness

For the thinner W-plan-form wing there is an increase in the lift-curve slope with Mach number; whereas the 12-percent-thick wing shows a gradual decrease of lift-curve slope with Mach number. (See fig. 11.) Theoretical lift slopes computed by the methods of reference 6 (applicable to very thin wings at subsonic speeds) are also shown in figure 11, and there is fairly good agreement with the results for the thinner wing. Very little effect of thickness is shown on the variation with Mach number of the lateral center of lift, although the bending-moment data are more linear with lift coefficient for the thinner wing. Theoretical center-of-lift locations (derived from ref. 6) show good agreement with experimental values.

The thinner (tapered in thickness) wing has more desirable pitching-moment characteristics in the low-lift range than the 12-percent-thick wing which has some unstable tendencies at Mach numbers near unity. Agreement with subsonic theory is very good, particularly for the thinner wing. Little effect of thickness was apparent on the higher-lift pitching-moment characteristics which is typical of conventional swept wings. Changes in the thickness of the W wings (fig. 11) did not produce as large an effect on the transonic lift and pitching-moment characteristics as these same thickness changes did for the conventional sweptback wings. (See figs. 9 and 10.)

The increase in minimum drag, due to a thickness change, at a relatively low supersonic Mach number over the subsonic drag level (pressure-drag increment between a Mach number of 0.75 and 1.05 at $C_L = 0$) can be estimated by use of the equation presented in reference 7. This equation states that this increment in drag is directly proportional to the square of the thickness. This value of drag predicted for the tapered-in-thickness W wing (using the root-mean-square thickness) is in very good agreement with the experimental result. (See fig. 11.)

Drag due to lift for the W wing with a tapered-in-thickness ratio is appreciably lower than that of the 12-percent-thick wing at Mach numbers of 1.00 and 1.05. This probably is due in a large measure to the smaller juncture losses of the thinner wing.

Effects of Sweep

As the sweep of the W-plan-form wings (10-percent root and 6-percent tip) is decreased from 45° to 35°, a tendency toward the bucket-type lift-slope variation can be noted at transonic speeds. (See fig. 12.) At subsonic speeds the agreement between theory and experiment is worse for the 35° sweep. The theoretical lateral-center-of-lift location is seen to be almost identical for the 35° and 45° W wings. The experimental

data, however, show the 35° wing to have a lateral-center-of-lift location that is 2 to 3 percent more outboard throughout the Mach number range.

A slight nonlinearity exists in the pitching-moment curve of the 35° W wing (fig. 12) in a range of Mach numbers from 0.90 to 1.00 at low lift coefficients. This is traceable to the aforementioned loss in lift at the juncture at transonic speeds. An increase in the sweep angle of the W plan form resulted in linear pitching-moment curves in the low- and moderate-lift range. At the highest Mach numbers the 35° wing shows very desirable high-lift pitching-moment characteristics, as indicated by the absence of pitch-up or pitch-down tendencies.

The expected earlier drag rise and greater minimum drag at low supersonic Mach numbers is apparent for the 35° W wing. The drag due to lift is slightly better for the 45° wing in the lower lift range for most of the Mach numbers.

CONCLUSIONS

An investigation was made to determine the transonic aerodynamic characteristics of three W-plan-form wings with an aspect ratio of 8, a taper ratio of 0.45, and NACA 63A-series airfoil sections. These results and results previously obtained on comparable sweptback wings indicate the following conclusions:

1. The large losses in lift-curve slope and concurrent unstable pitching-moment tendencies of thick sweptback wings in the low-lift range at transonic speeds were appreciably alleviated by modification of the wing to the W plan form. The modification also provided a significant improvement in the pitching-moment characteristics at moderate and high lifts.

2. The minimum drag coefficients in the transonic speed range were somewhat higher for the W-plan-form wings than for the comparable sweptback wings.

3. The effects of thickness changes on the transonic lift and pitching-moment characteristics of the W wings were appreciably smaller than for the conventional sweptback wings of the same aspect ratio.

4. Subsonic lift-curve slopes, aerodynamic center, and lateral-center-of-pressure locations for the W-plan-form wings could be predicted rather well by use of available theory.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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2. Campbell, George S., and Morrison, William D., Jr.: A Small-Scale Investigation of "M" and "W" Wings at Transonic Speeds. NACA RM L50H25a, 1950.

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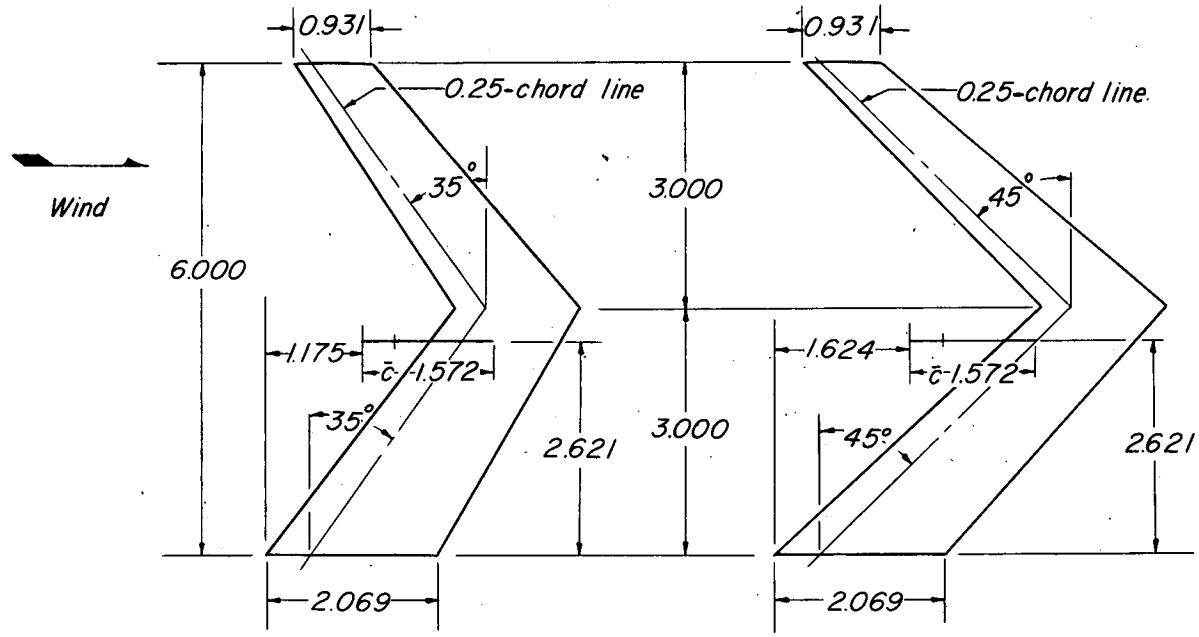


Tabulated Wing Data

Area(Twice semispan)	0.125 sq ft
Aspect ratio	8
Taper ratio	0.45
Airfoil section parallel to free stream	NACA 63A-series

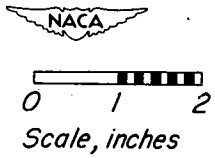


Figure 1.- Plan-form drawing of W wings having 35° and 45° sweep of the quarter-chord line.

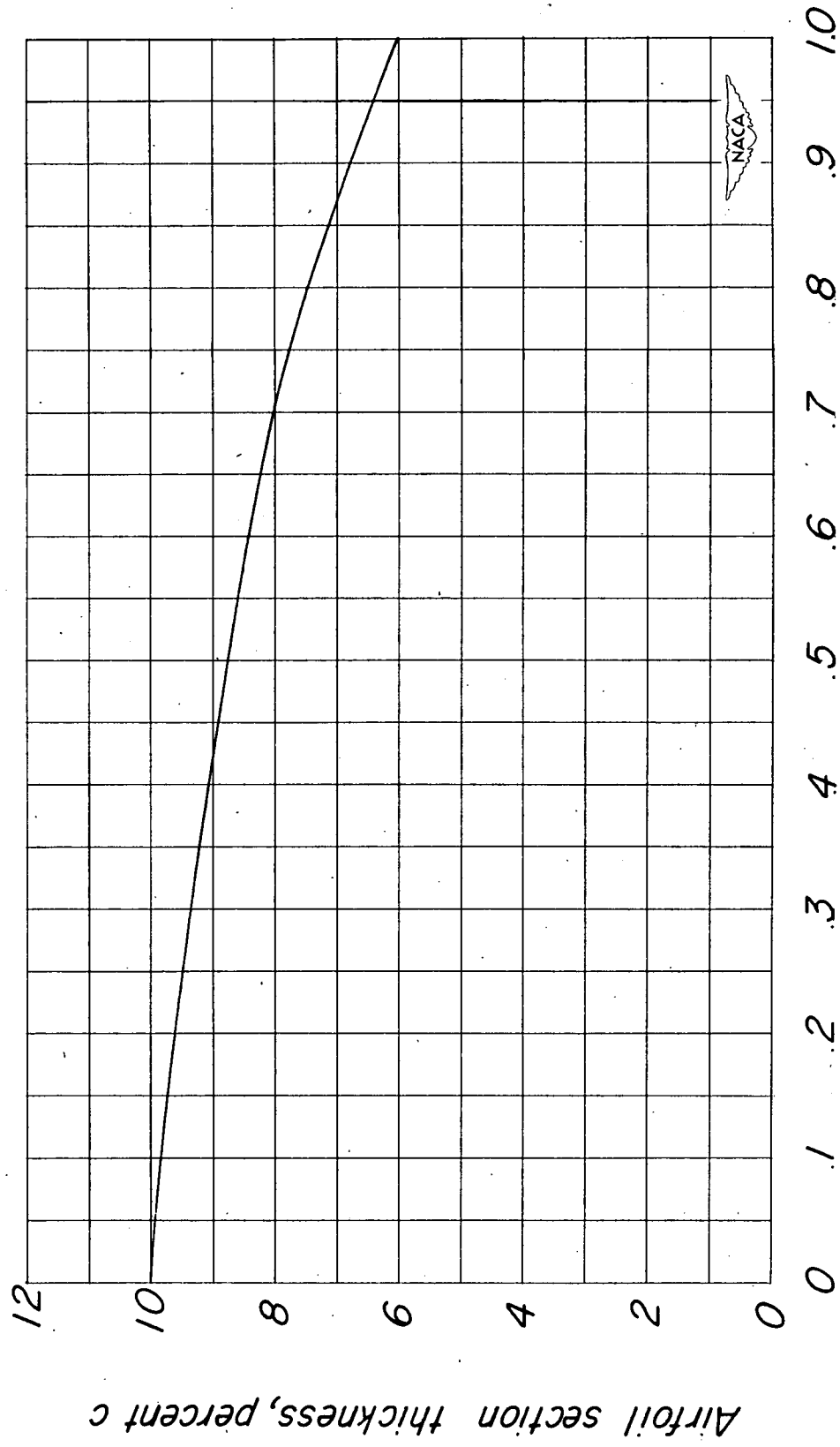


Figure 2.- Spanwise distribution of thickness ratio for W-wing models having tapered thickness ratio.

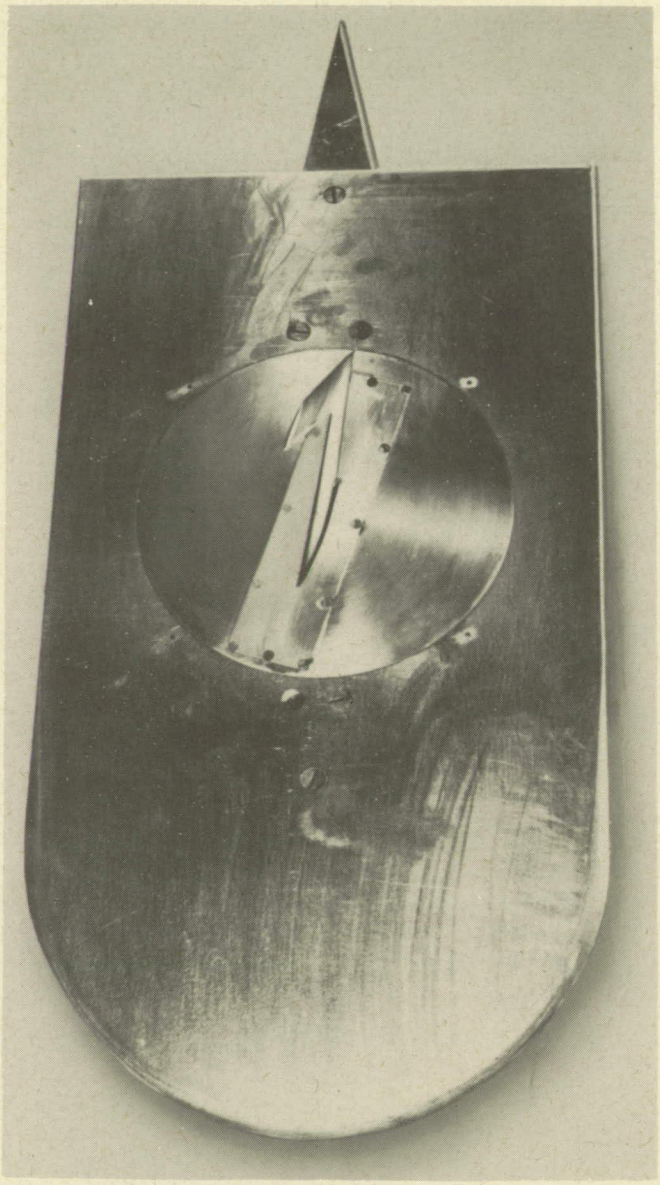


Figure 3.- W wing mounted on the reflection plane. L-64860.1

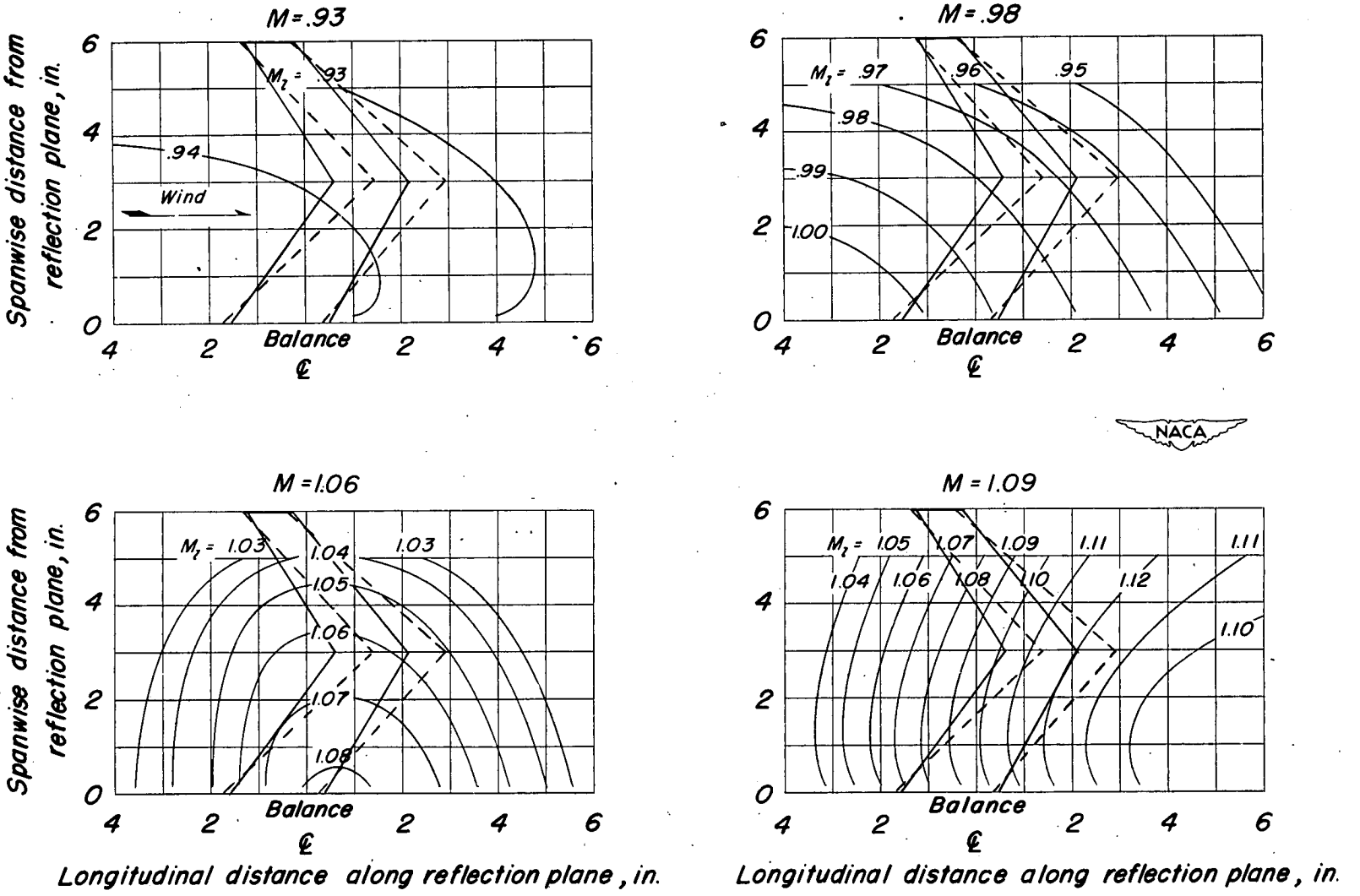


Figure 4.- Typical Mach number contours in the testing region of the semispan models.

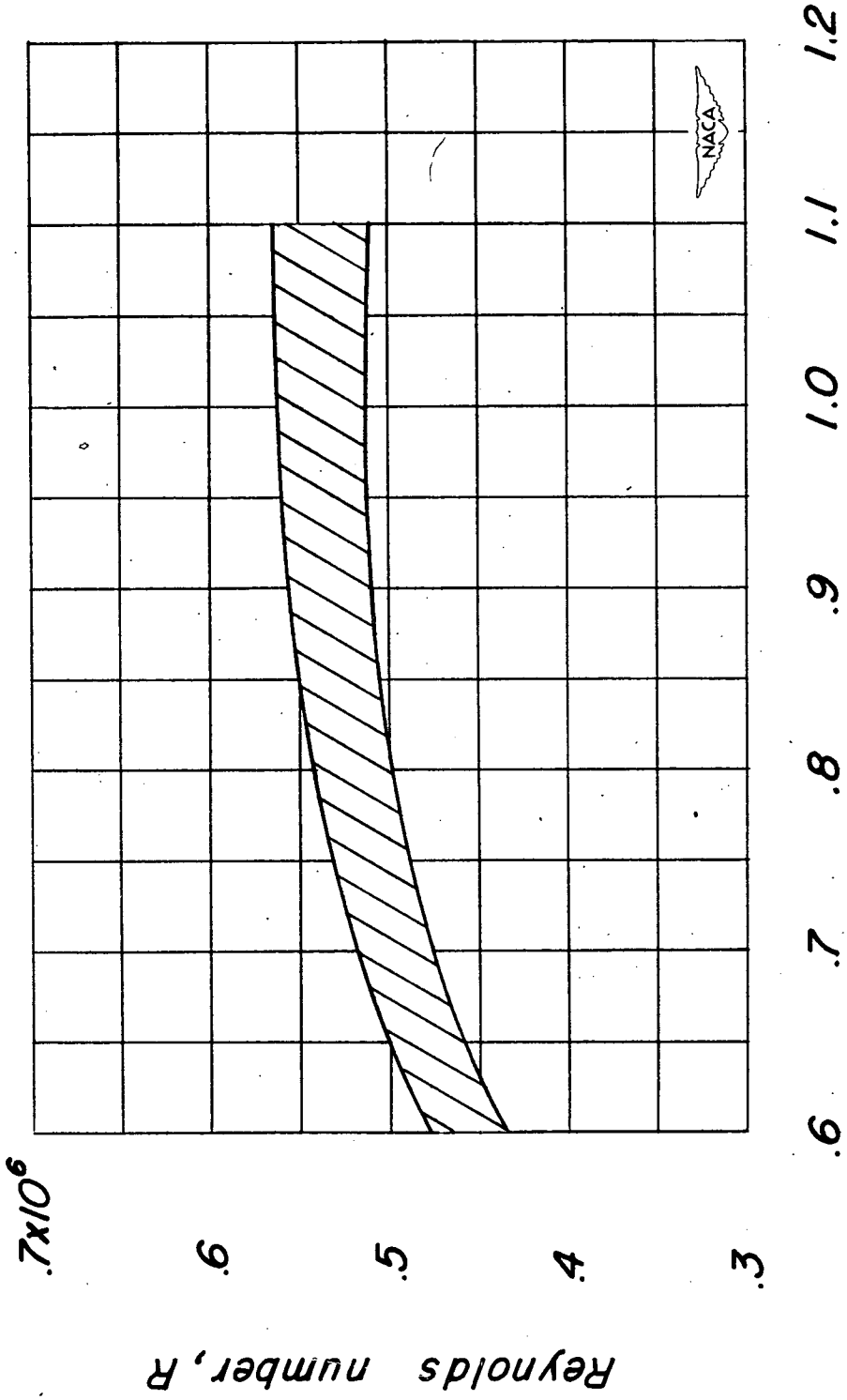
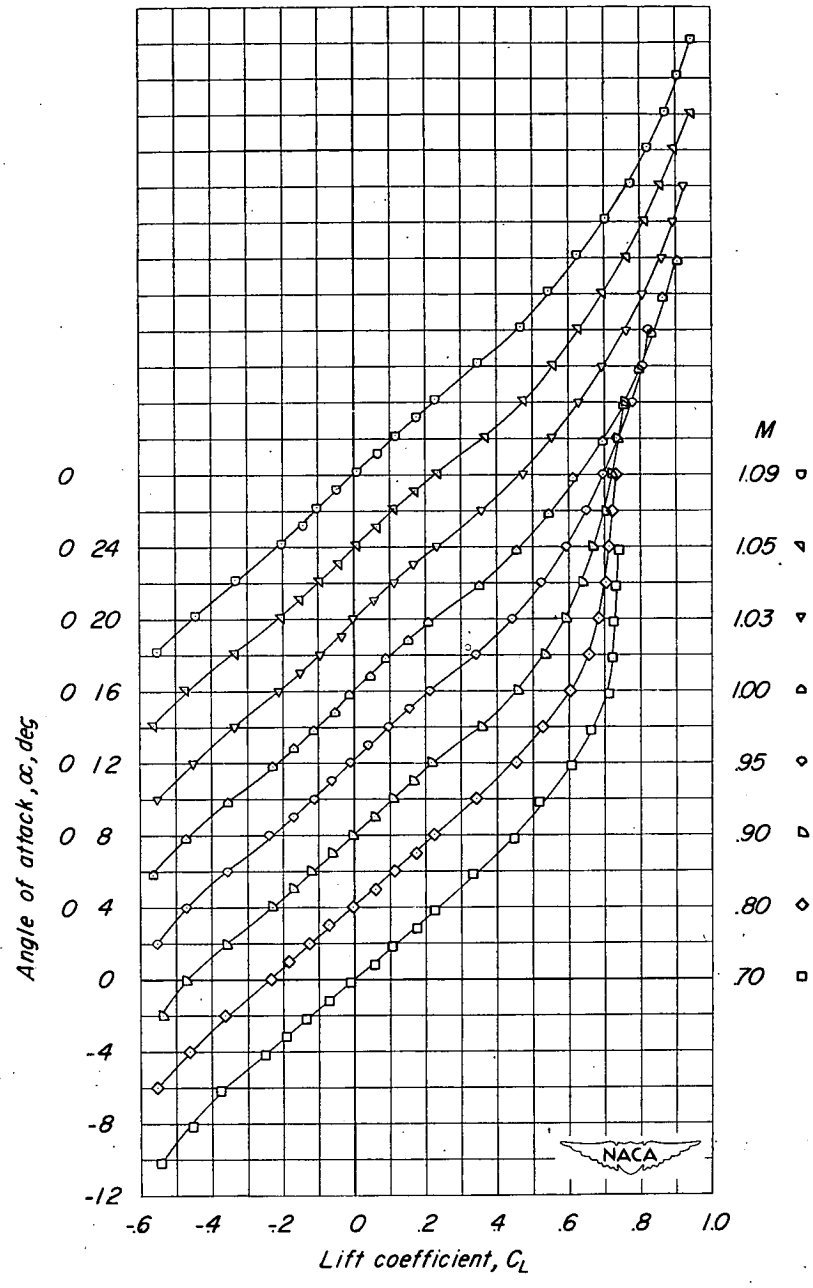
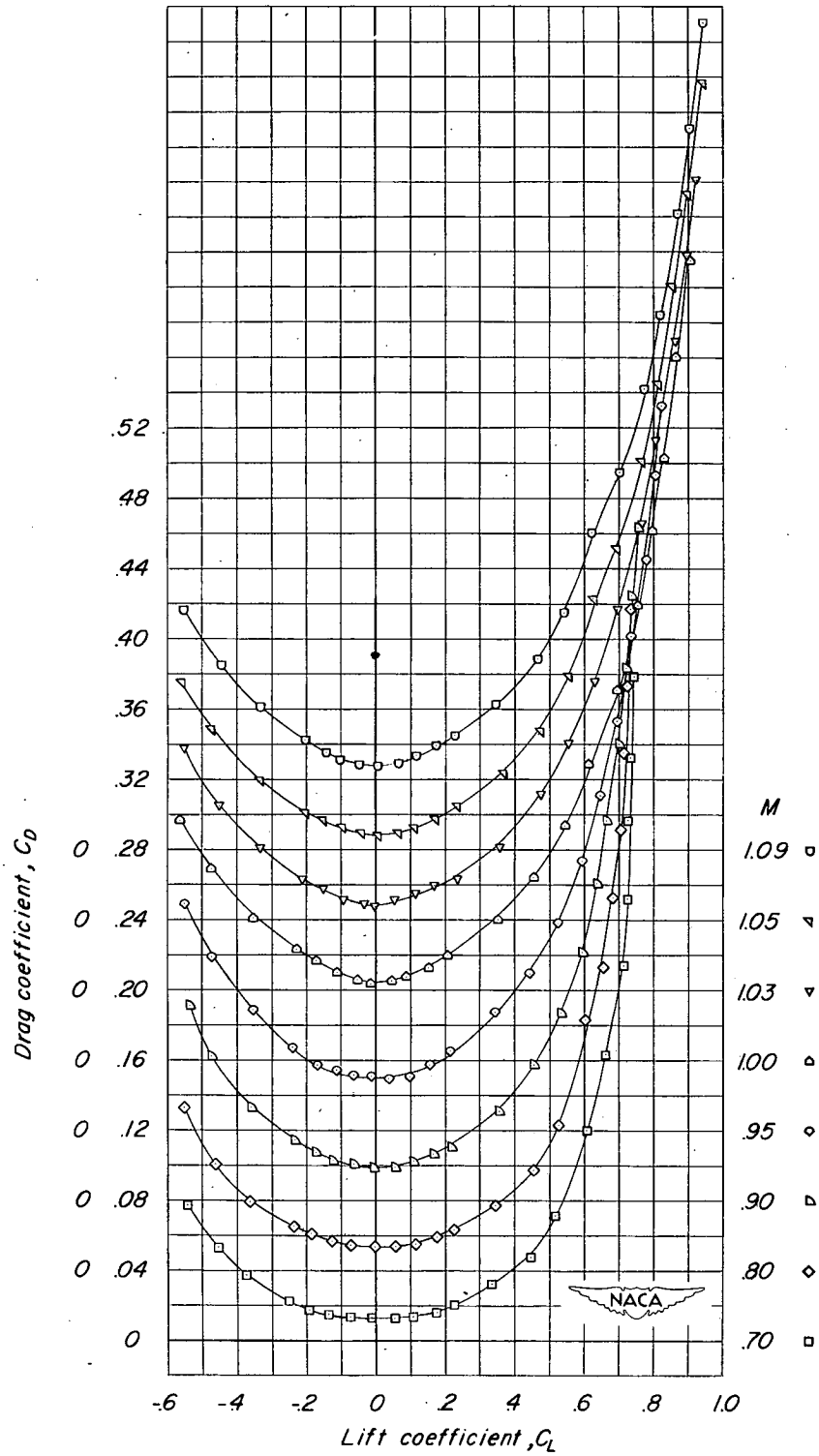


Figure 5.- Range of test Reynolds numbers at test Mach numbers for the models of this investigation and comparison models.



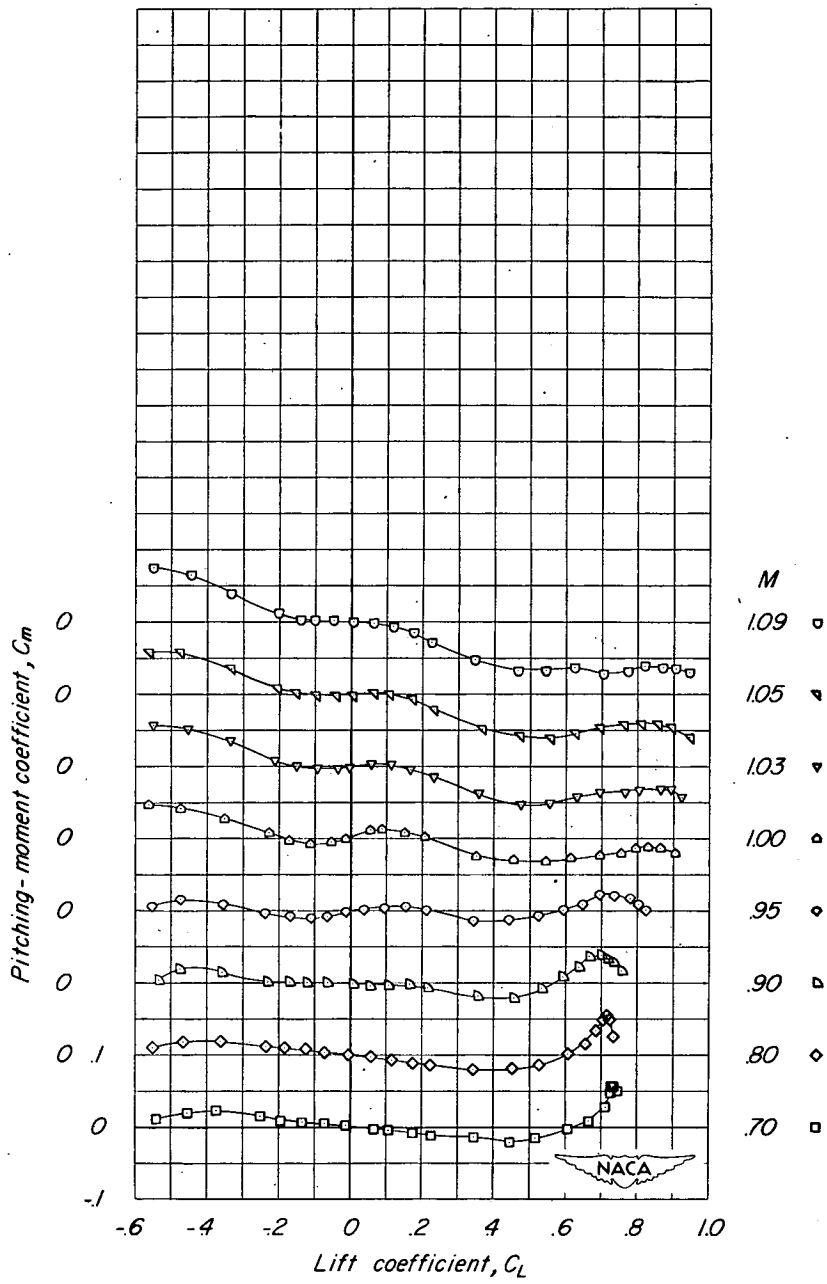
(a) α against C_L.

Figure 6.- Aerodynamic characteristics of a W wing having 45° sweep of the quarter-chord line, aspect ratio 8, taper ratio 0.45, and an NACA 63_1A012 airfoil section.



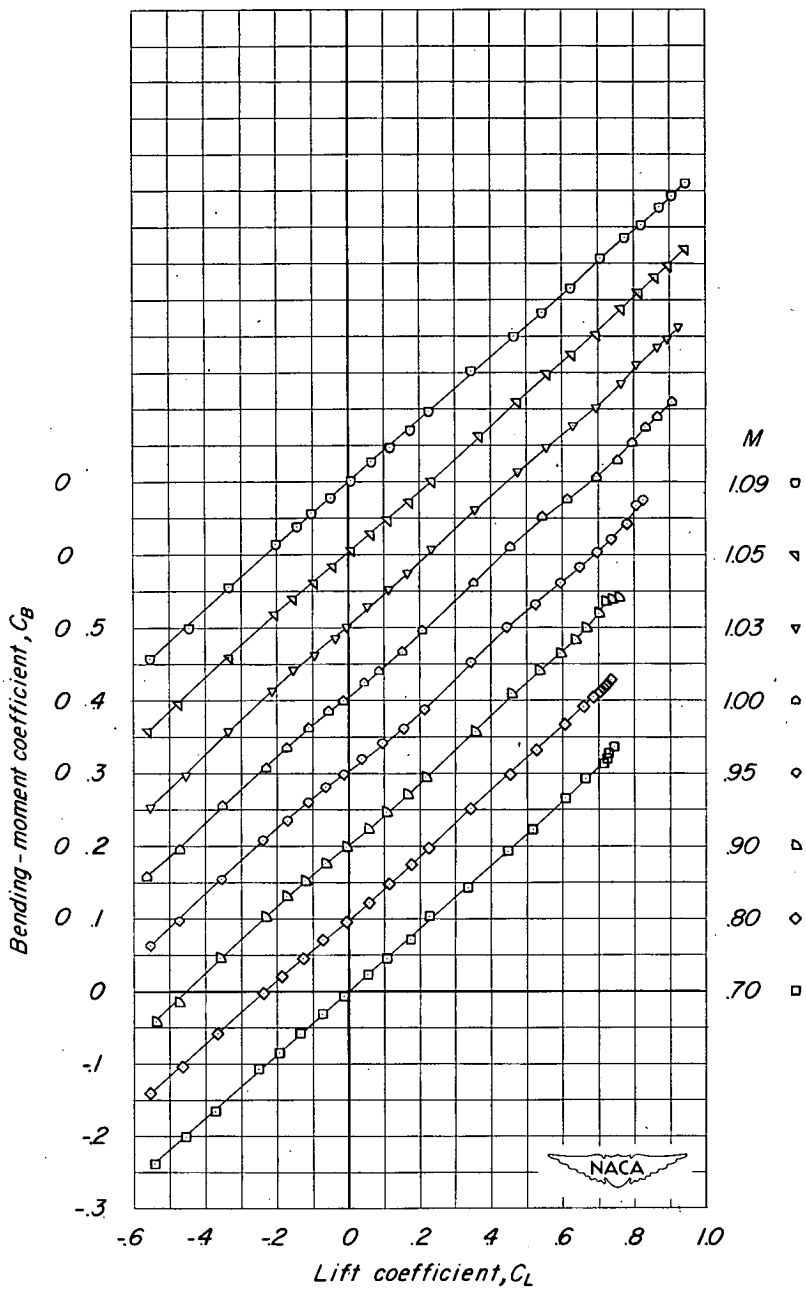
(b) C_D against C_L.

Figure 6.- Continued.



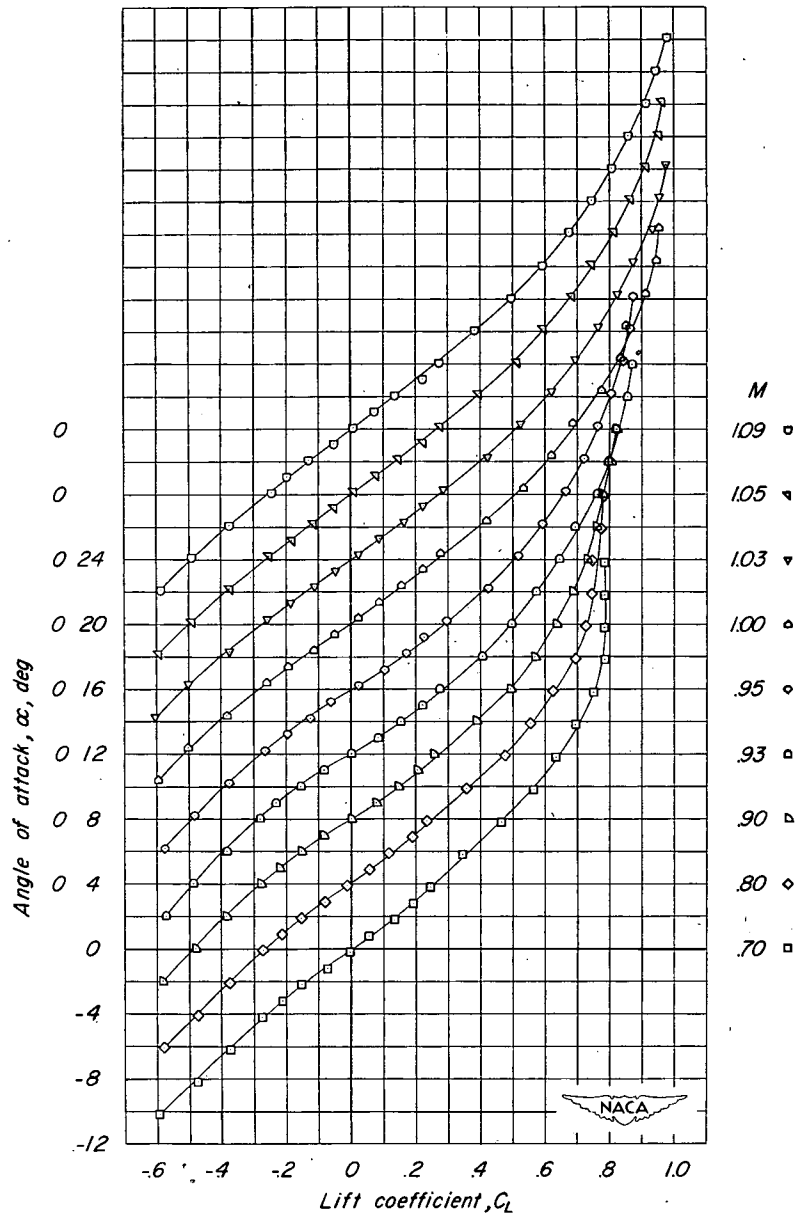
(c) C_m against C_L.

Figure 6.- Continued.



(d) C_B against C_L.

Figure 6.- Concluded.



(a) α against C_L.

Figure 7.- Aerodynamic characteristics of a W wing having 45° sweep of the quarter-chord line, aspect ratio 8, taper ratio 0.45, and an NACA 63A010 airfoil section at the root tapered to an NACA 63A006 airfoil section at the tip.

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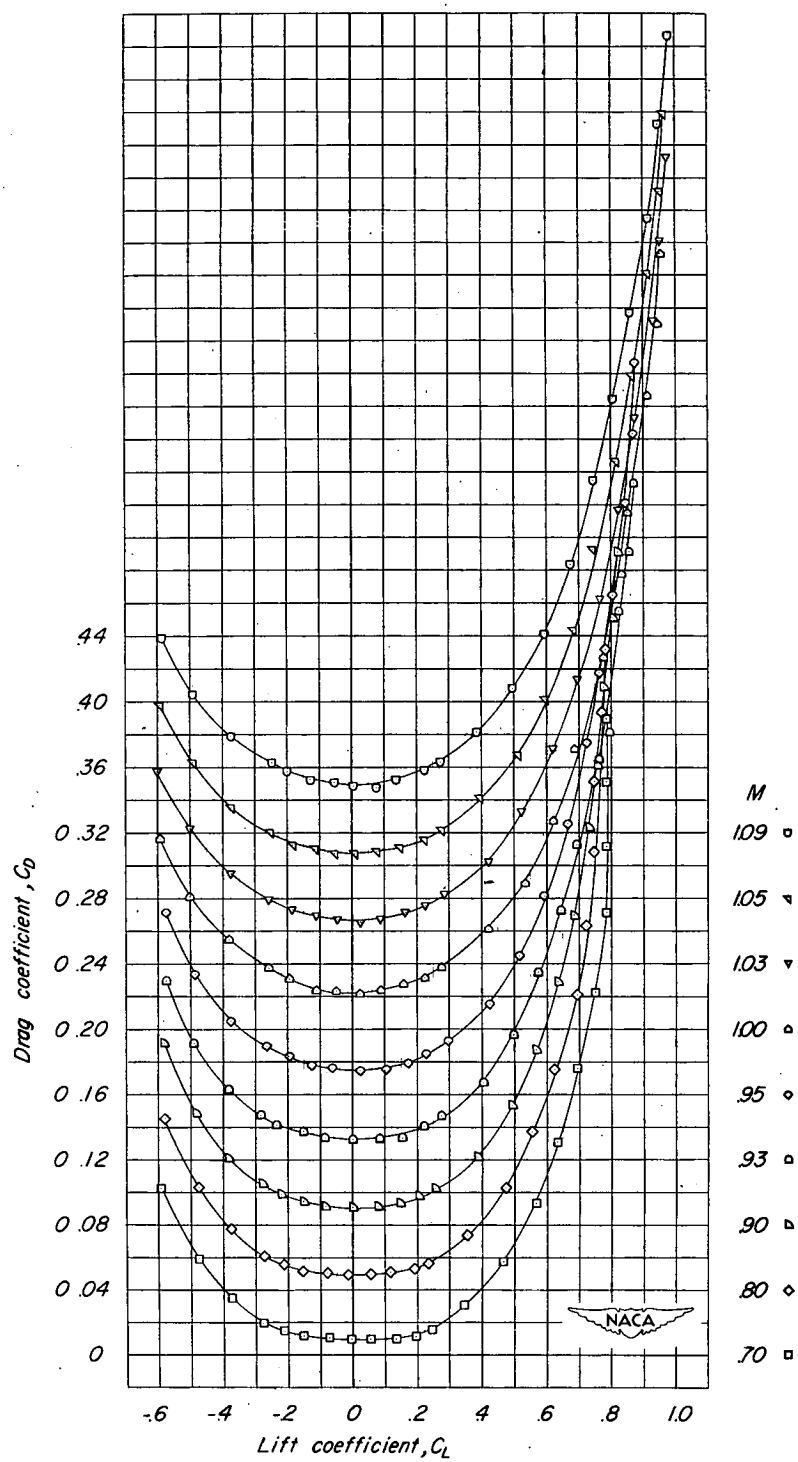
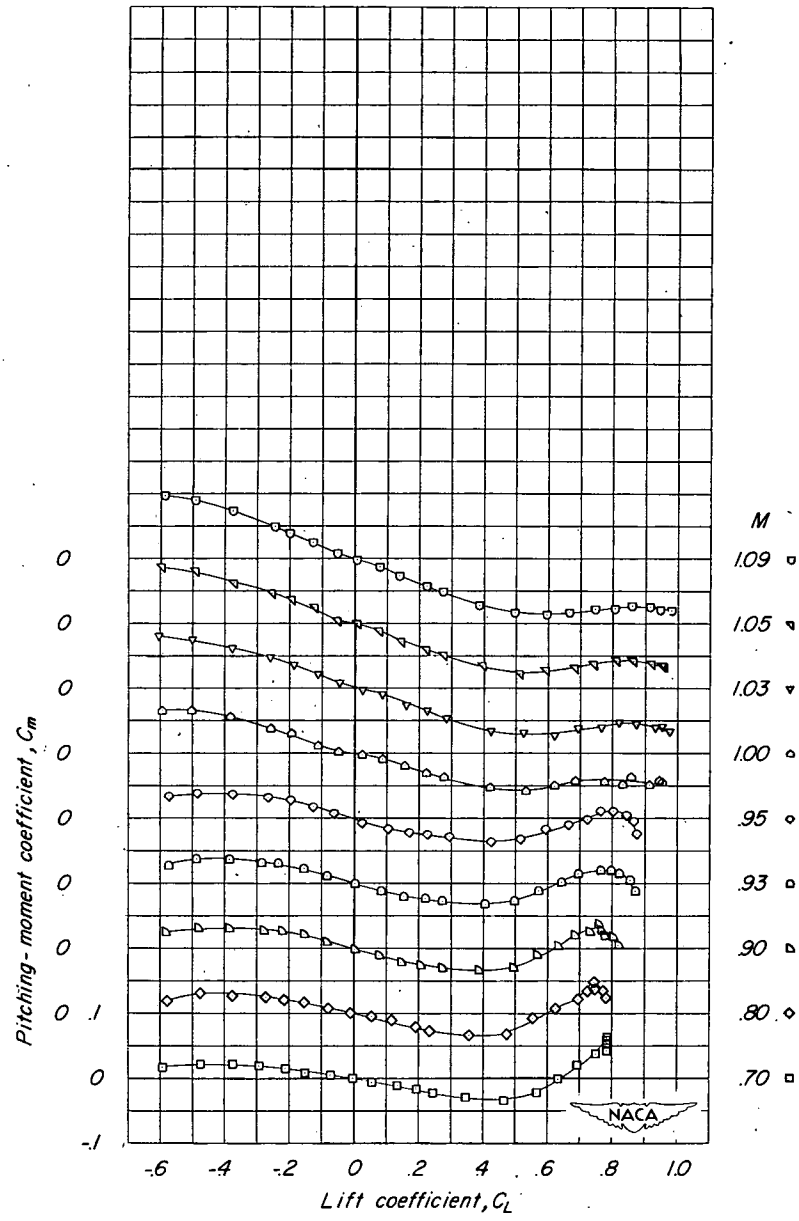


(b) C_D against C_L.

Figure 7.- Continued.



(c) C_m against C_L.

Figure 7.- Continued.

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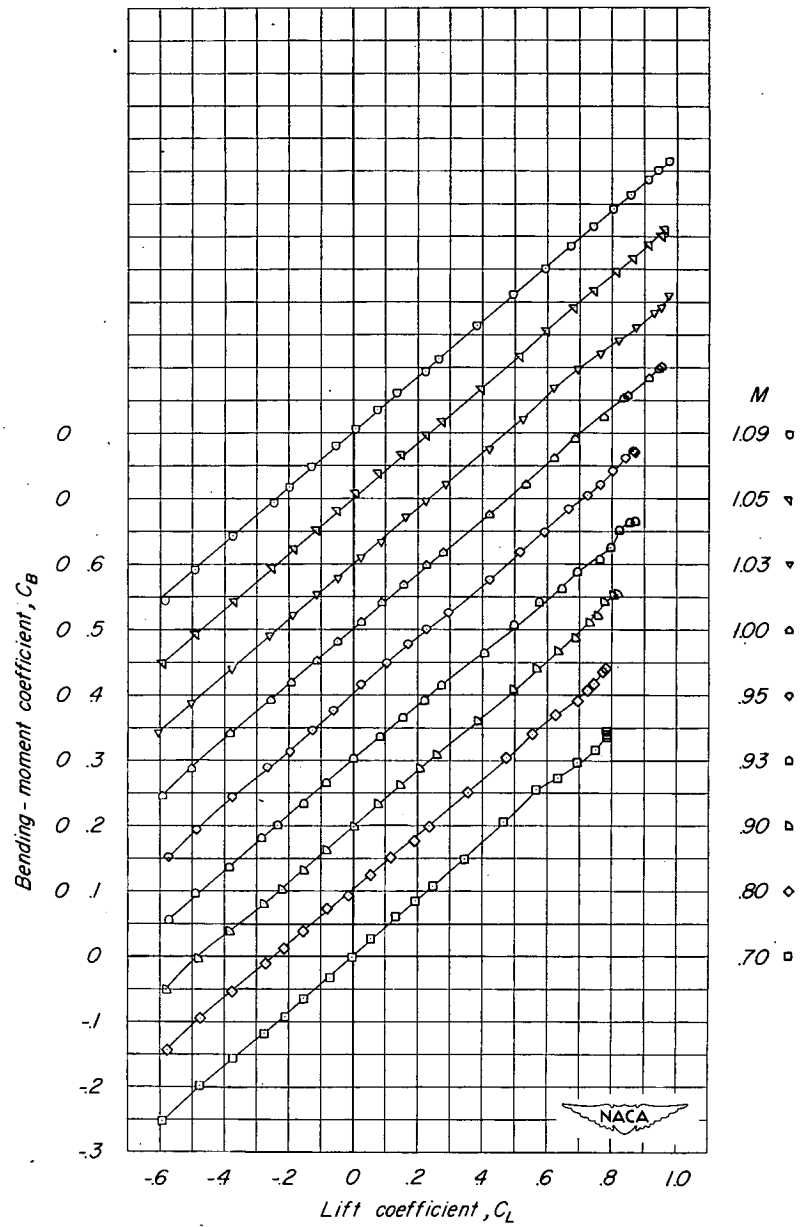
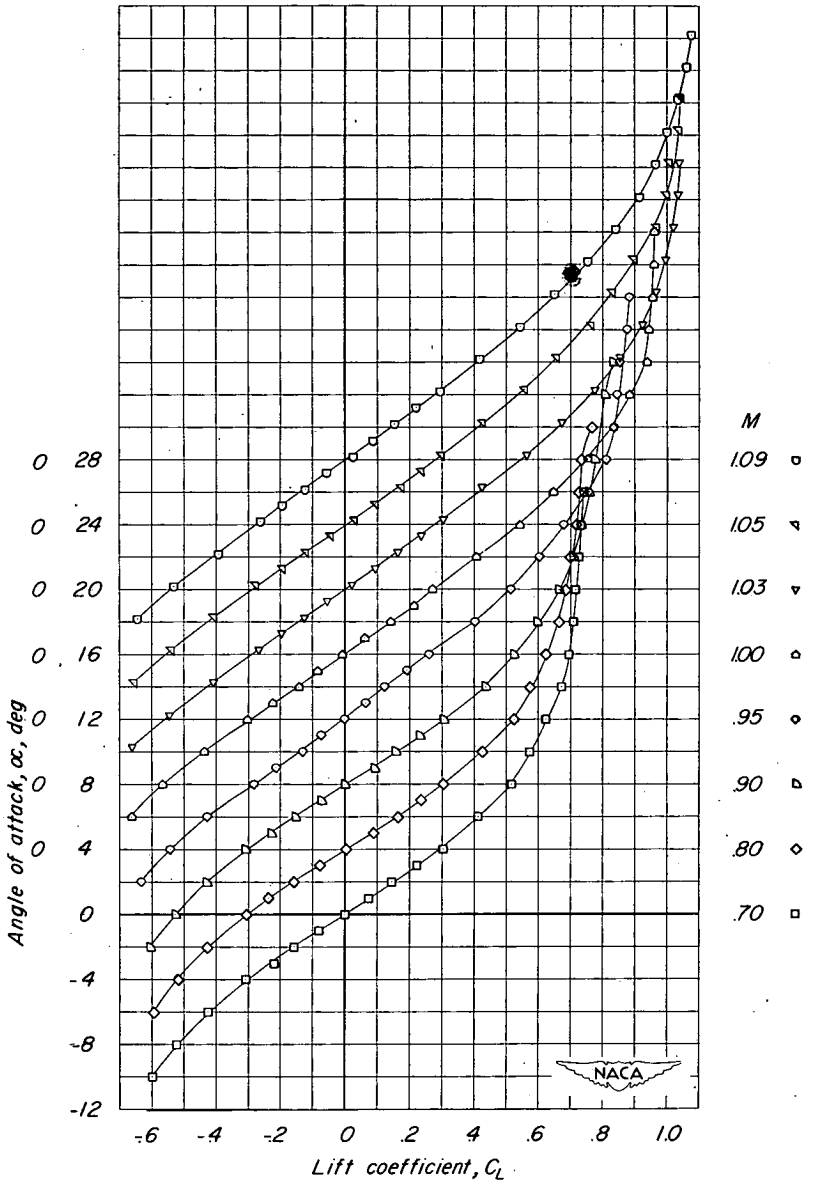


(d) C_B against C_L.

Figure 7.- Concluded.



(a) α against C_L.

Figure 8.- Aerodynamic characteristics of a W wing having 35° sweep of the quarter-chord line, aspect ratio 8, taper ratio 0.45, and an NACA 63A010 airfoil section at the root tapered to an NACA 63A006 airfoil section at the tip.

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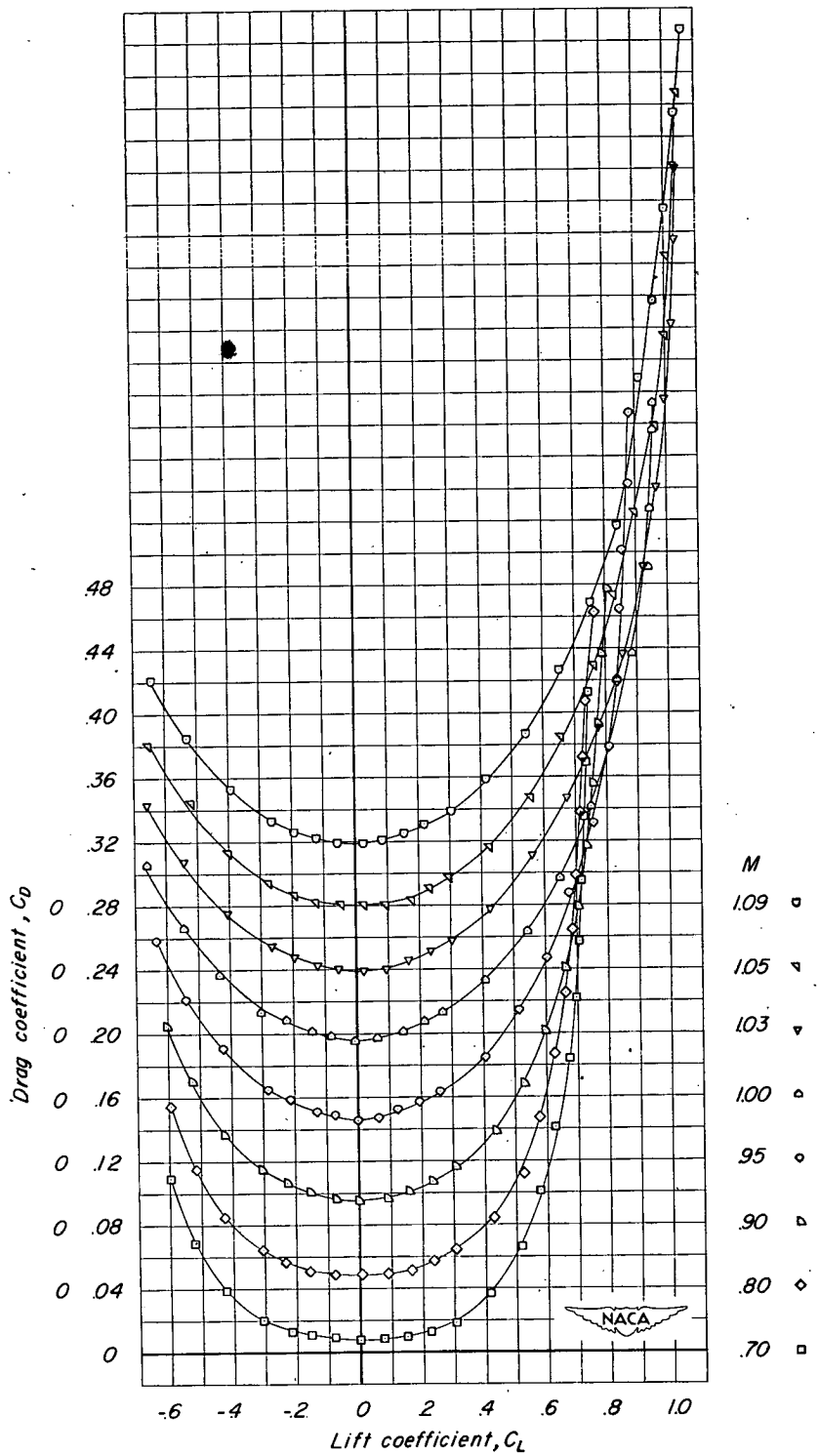
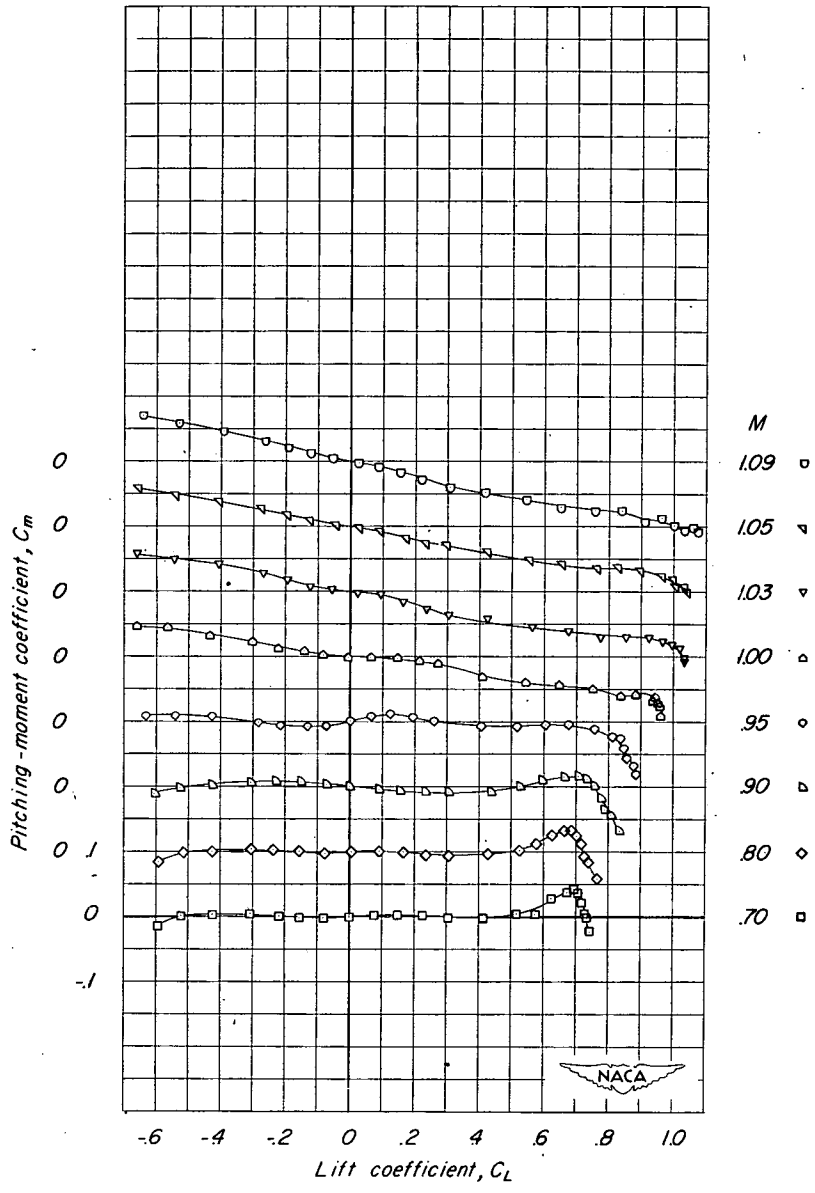


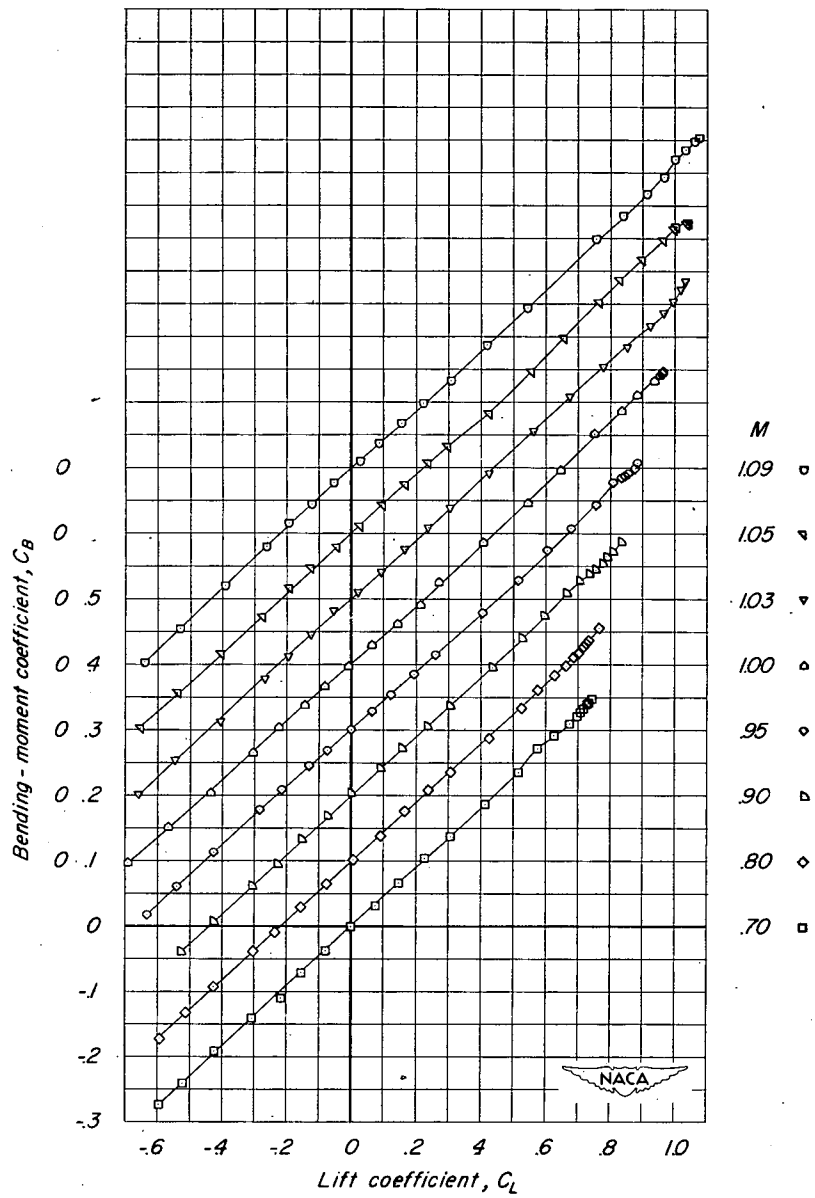
(b) C_D against C_L.

Figure 8.- Continued.



(c) C_m against C_L.

Figure 8.- Continued.



(d) C_B against C_L.

Figure 8.- Concluded.

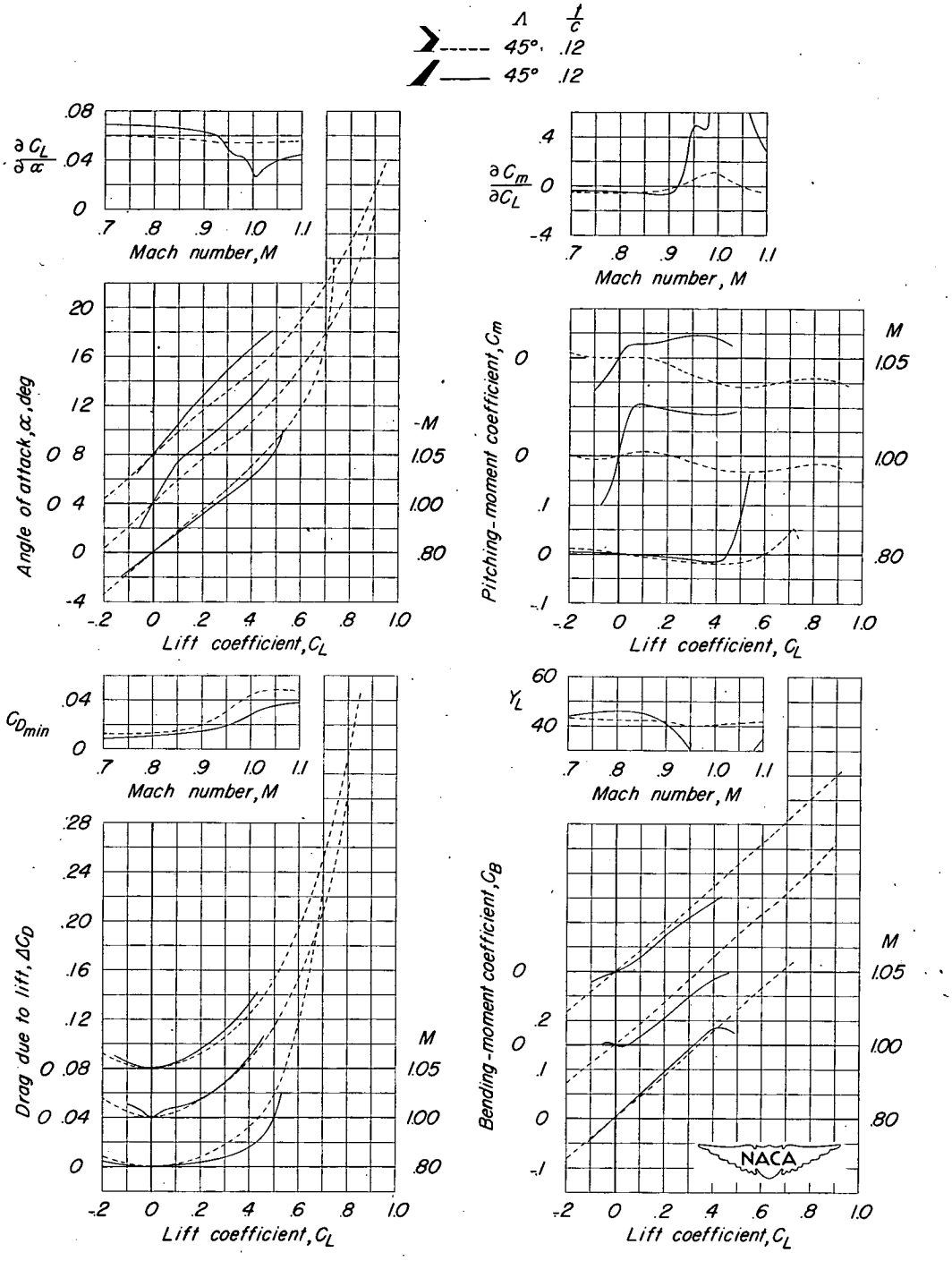


Figure 9.- Comparison of the aerodynamic characteristics of a W wing and conventional sweptback wing of aspect ratio 8, taper ratio 0.45, and thickness ratio 0.12 (constant).

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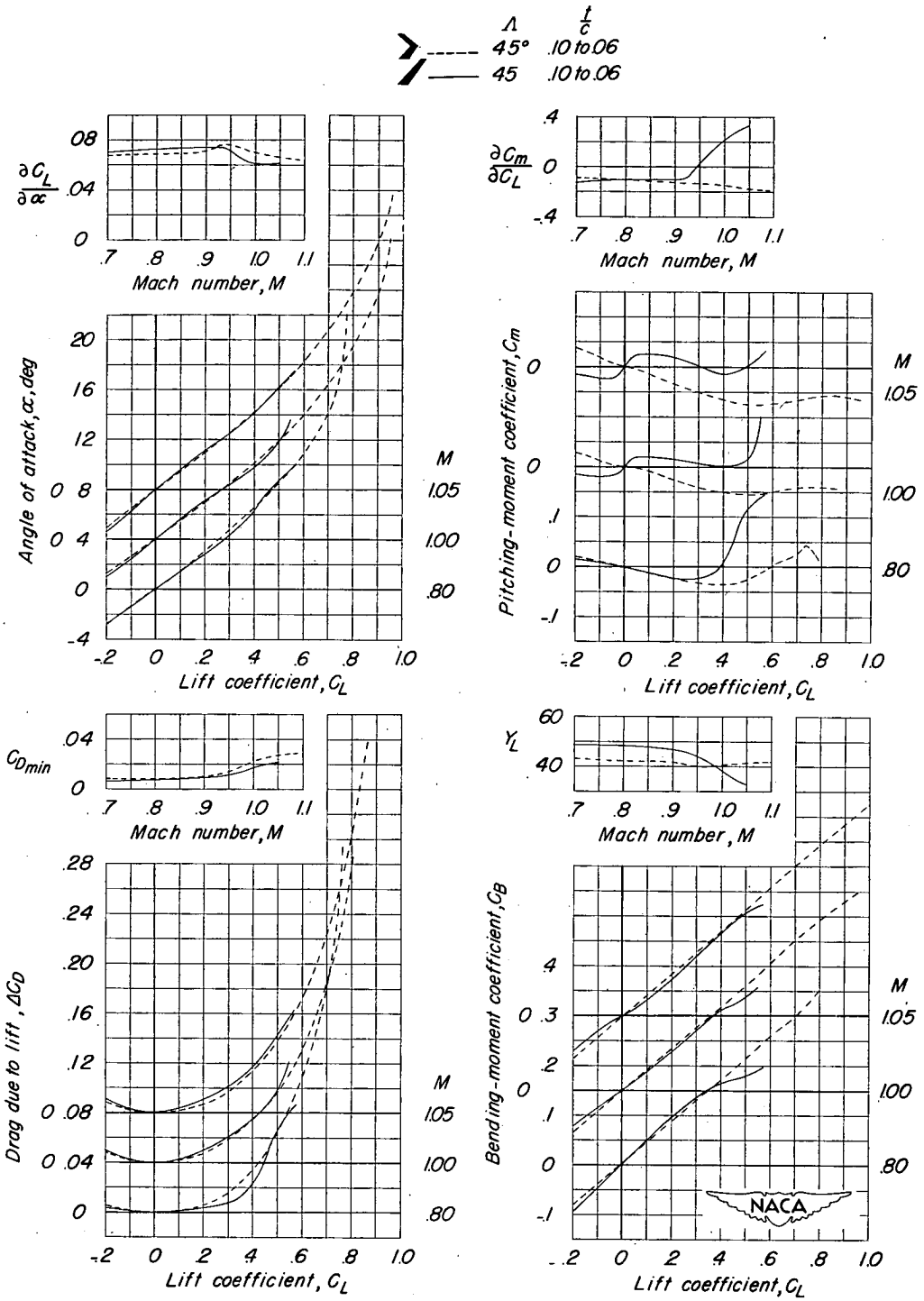

Figure 10.- Comparison of the aerodynamic characteristics of a W wing and conventional sweptback wing of aspect ratio 8, taper ratio 0.45, and thickness ratio from 0.10 at root to 0.06 at the tip.

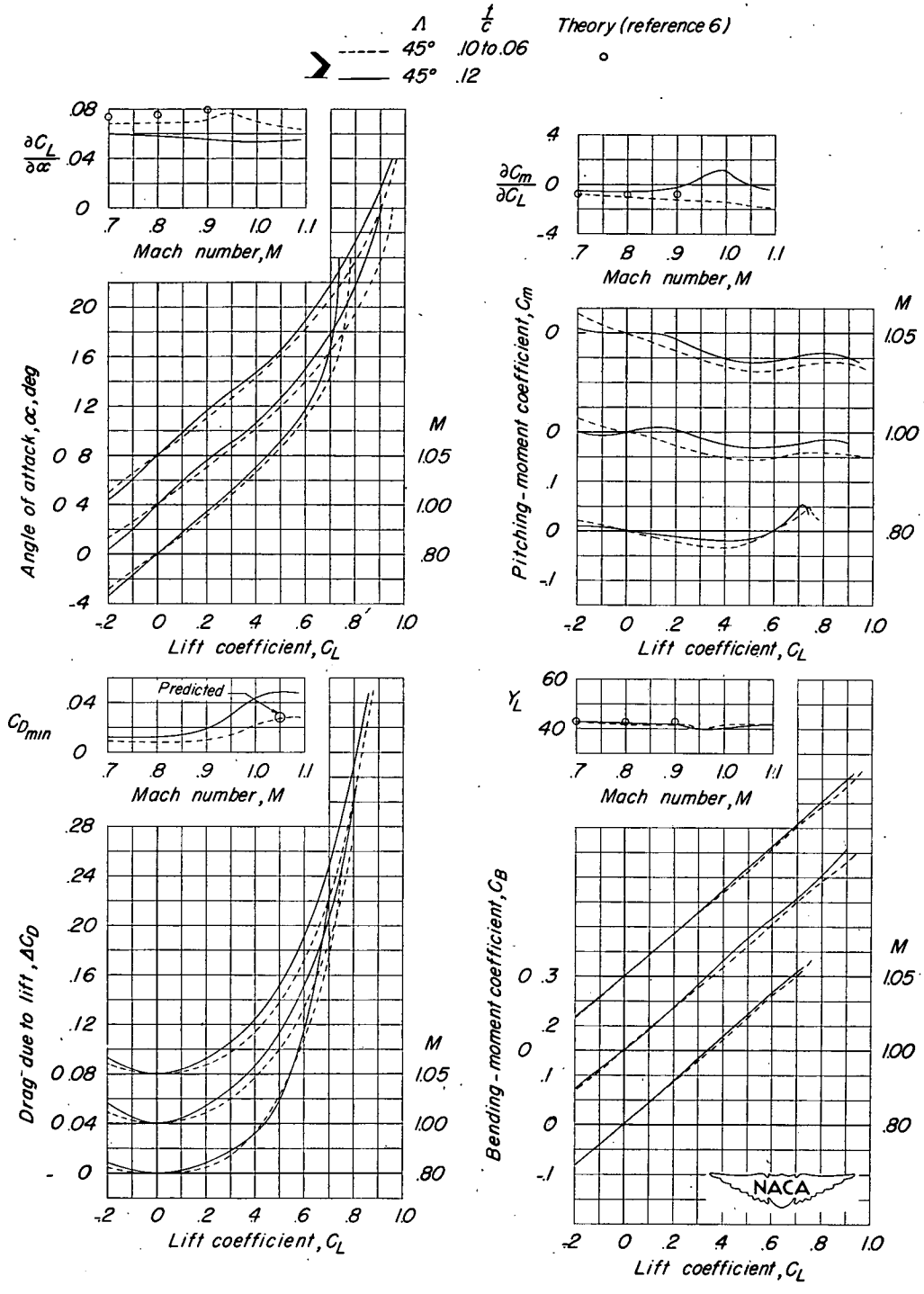

Figure 11.- Comparisons of the effects of thickness on the aerodynamic characteristics of W wings of aspect ratio 8 and taper ratio 0.45.

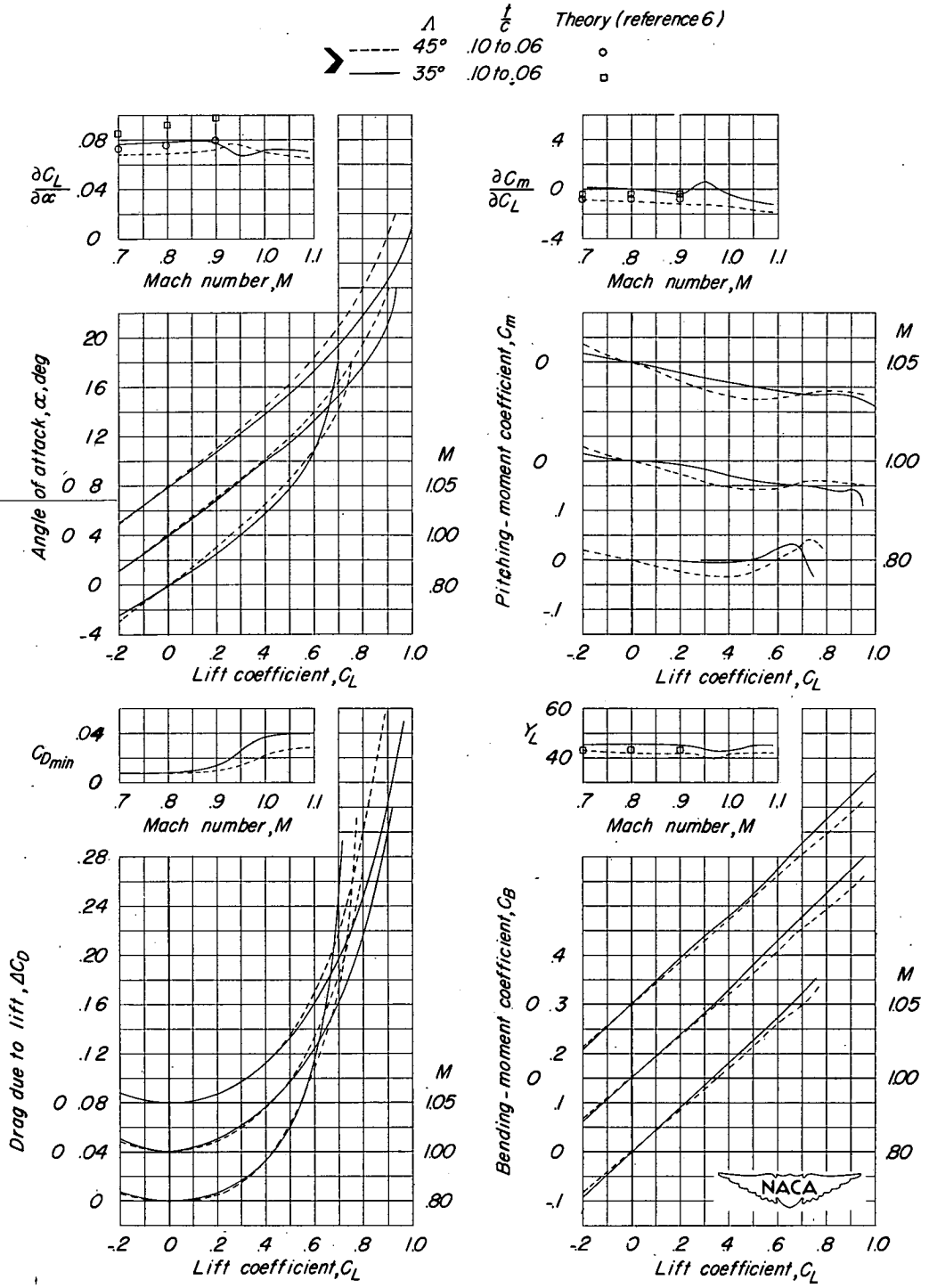

Figure 12.- Comparisons of the effects of sweep on the aerodynamic characteristics of W wings of aspect ratio 8 and taper ratio 0.45.